PB89-120869

Overview of EPA's (Environmental Protection Agency's) Program for Retrofit Sorbent Injection Technologies

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Nov 88

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA (Please read Instructions on the reverse before completing)		
1. REPORT NO. EPA/600/D-88/232	2.	3. RECIPIENT'S ACCESSION NO. PB89-120869/AS
4. TITLE AND SUBTITLE An Overview of EPA's Program for Retrofit Sorbent Injection Technologies		5. REPORT DATE November 1988
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Richard D. Stern		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS See Block 12		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. NA (Inhouse)
12. SPONSORING AGENCY NAME AND ADDRESS **EPA, Office of Research and Development** Air and Energy Engineering Research Laboratory **Research Triangle Park, NC 27711**		13. TYPE OF REPORT AND PERIOD COVERED Published paper
		14. SPONSORING AGENCY CODE **EPA/600/13**

15. SUPPLEMENTARY NOTES AEERL project officer is Richard D. Stern, Mail Drop 63, 919/541-2973.

16. ABSTRACT The paper is an overview of EPA's research program to develop improved control technologies for emissions of sulfur dioxide (SO2) and nitrogen oxides (NOx) from the combustion of fossil fuels. Analysis indicates that low capital cost technology for retrofit to existing boilers would provide flexibility in control strategy even at moderate (e.g., 50%) SO2 removal rates. One such technology that EPA is evaluating is Limestone Injection Multistage Burner (LIMB). LIMB combines sorbent injection for SO2 control with the use of low-NOx burners, in which staged combustion is utilized for NOx control. EPA is also evaluating E-SOx and ADVACATE (ADVAnced SiliCATE) technologies. E-SOx combined advanced electrostatic precipitator (ESP) technology and spray dryer technology to remove particulate matter and SO2 in the same physical equipment. The ADVACATE process is based on the in-duct injection of a highly reactive calcium sorbent for SO2 control. The process may be used alone or in combination with LIMB to enhance performance. EPA's program for research and development, field evaluation, and demonstration of LIMB, E-SOx, and ADVACATE technologies is described and program objectives, approaches, current status and results, future activities, and schedules are presented for these programs.

17. KEY WORDS AND DOCUMENT ANALYSIS			
a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Electrostatic Precipitators	Pollution Control	13B
Sorbents		Stationary Sources	11G 13I
Sulfur Oxides	Silicate Minerals	Acid Rain	07B
Nitrogen Oxides	Precipitation (Meteorology)	Limestone Injection Multistage Burners (LIMB)	21D 04B
Fossil Fuels		E-SOx Process	21B
Combustion	Acidification	ADVACATE Process	08G
Limestone			
18. DISTRIBUTION STATEMENT **Release to Public**		19. SECURITY CLASS (This Report) **Unclassified**	21. NO. OF PAGES 23
		20. SECURITY CLASS (This page) **Unclassified**	22. PRICE A03 $13.95

EPA Form 2220-1 (9-73)

PB89-120869

EPA/600/D-88/232
November 1988

AN OVERVIEW OF EPA'S PROGRAM FOR RETROFIT SORBENT INJECTION TECHNOLOGIES

By

Richard D. Stern
Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

AIR AND ENERGY ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

AN OVERVIEW OF EPA'S PROGRAM FOR RETROFIT SORBENT INJECTION TECHNOLOGIES

Richard D. Stern
Technology Applications Branch
Air and Energy Engineering Research Laboratory
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina

The U. S. Environmental Protection Agency (EPA) is engaged in a research program to develop improved control technologies for emissions of sulfur dioxide and nitrogen oxides (SO_2 and NO_x) from the combustion of fossil fuels. Control of these emissions is important because of their magnitude and apparent link to acid rain. While the cause of acid rain and its potential solution are still being debated, control of SO_2 and NO_x from power plants continues to be a major element in all proposed control strategies.

Control techniques for acid rain will likely include a combination of technologies to achieve the mandated pollutant reduction at a cost that will minimize the impact on the nation and on specific geographical areas. Analysis indicates that low capital cost technology for retrofit to existing boilers would provide flexibility in control strategy even at moderate (e.g., 50%) SO_2 removal rates. One such technology that EPA is evaluating is LIMB (Limestone Injection Multistage Burner). LIMB combines sorbent injection for SO_2 control with the use of low-NO_x burners, in which staged combustion is utilized for NO_x control. EPA is also evaluating E-SO_x and ADVACATE (ADVAnced SiliCATE) technologies. E-SO_x combines advanced electrostatic precipitator (ESP) technology and spray dryer technology to remove particulate matter and SO_2 in the same physical equipment. The ADVACATE process is based on the in-duct injection of a highly reactive calcium sorbent for SO_2 control. The process may be used alone or in combination with LIMB to enhance performance.

EPA's program for R&D, field evaluation, and demonstration of LIMB, E-SO_x, and ADVACATE technologies is described and program objectives, approaches, current status and results, future activities, and schedules are presented for these programs.

Introduction

Sulfur dioxide and nitrogen oxides, SO_2 and NO_x, are two major pollutants resulting from fuel combustion. Coal-fired utility boilers account for about 65% of the SO_2 and 29% of the NO_x emissions in the United States.[1] These two pollutants are generally believed to be major precursors of acid rain and their control is a significant concern of the U. S. Environmental Protection Agency, the utility industry, and other private and public organizations.

The national strategy for reducing acid rain is still being debated in Congress; the debate centers on reduction of current SO_2 emissions to 5 to 12 million tons* per year and on reduction of NO_x as an SO_2 offset or by a fixed amount nationally. The choice of a strategy will determine the control techniques for limiting SO_2 and NO_x emissions from utility boilers and will most likely include a mix of technologies to achieve the desired reduction at minimum cost. Of the existing commercial control options, flue gas desulfurization (FGD) is costly, and switching to a lower sulfur content fuel may have severe socioeconomic and logistic impacts. Only about 10% of the boilers east of the Mississippi River, where the impact of acid rain is felt most, are subject to New Source Performance Standards.[2] Most of the remaining 90% are older units having a useful life of 10 to 30 years. An effective control technology for these boilers would result in significant reduction of national SO_2 and NO_x emissions. There is a need, therefore, for lower cost control technologies which can be retrofitted to this existing boiler population.

The Environmental Protection Agency has been working on three such technologies:

1. LIMB (Limestone Injection Multistage Burner) which is based on the injection of a dry sorbent into the boiler for direct capture of SO_2 in the flue gas, combined with the use of low-NO_x burners for reduction of NO_x emissions.

2. E-SO_x which combines spray dryer technology with advanced electrostatic precipitator (ESP) technology to remove SO_2 and particulate matter in the modified ESP.

3. ADVACATE (ADVAnced siliCATE) which is based on in-duct injection of a highly reactive calcium sorbent for SO_2 control.

This paper will describe these program areas and provide an overview of objectives, approach, current status, and plans for each.

LIMB

Building on attempts made in the early 70s, EPA initiated a research and development program in 1981 to improve the LIMB process and bring the technology to a commercial scale. Current emphasis is on large scale prototype testing and full-scale demonstrations with supporting research activities.

In the LIMB process, shown schematically in Figure 1, a sorbent is injected into the boiler at a location which will provide the optimum time/temperature for reaction to remove 50-70% of the sulfur present. The NO_x is controlled by utilizing a specially designed burner in the boiler. Two major design types are being addressed: 1) wall-fired boilers, and 2) tangentially fired boilers. Each type is about 45% of the existing population and there are significant differences between them with respect to their firing systems, and resultant changes in combustion conditions. Commercial scale wall-fired and tangentially fired demonstrations, and a large-scale prototype evaluation are currently underway.

The basic goals of the LIMB demonstrations are to extend technology development to full-scale applications on representative utility boilers. The successful retrofit of LIMB to an existing boiler is expected to demonstrate that:

1. SO_2 reduction of 50% or more and NO_x emissions of less than 0.5 $lb/10^6$ Btu can be achieved at a fraction of the cost of add-on FGD systems.

2. Boiler reliability, operability, and steam production can be maintained at levels existing prior to LIMB retrofit.

3. Technical difficulties attributable to LIMB operation, such as additional slagging and fouling, changes in ash disposal requirements, and an increased particulate load, can be resolved in a cost-effective manner.

Each demonstration project consists of several distinct phases: a preliminary phase to develop the LIMB process design specifically for the host boiler, a construction and start-up phase, and an operating and evaluation phase.

The goals of the prototype activity are essentially the same. However, in contrast to the demonstrations, the tangentially fired prototype effort is not an evaluation of a single point design but an evaluation under different design and operating conditions including several coals and sorbents. The three programs are discussed below:

Wall-Fired LIMB Demonstration[1]

This demonstration is a 4-year project that includes design installation, operation, and testing of a LIMB system at the 105 MW, Unit 4 boiler at Ohio Edison's Edgewater Station in Lorain, OH. The primary fuel being used is an Ohio bituminous coal having a nominal sulfur content of 3%. EPA is sharing the cost of the project with the major participants: the State of Ohio, Ohio Edison, Babcock & Wilcox (B&W), and Consolidation Coal.

The process design was completed and the LIMB system installed at Edgewater in 1987. A short series of tests were conducted with the low-NO_x XCL burners in order to allow comparison with data obtained on the circular burners they had replaced in 1986. As can be seen in Figure 2, NO_x emissions with the XCL burners achieved the project goal of 0.5 $lb/10^6$ Btu over the full operating range of the boiler. This performance

represents approximately 40-50% reduction when compared to data on the circular burners. Further burner tests are planned after optimization of sorbent injection. The system was started up in July 1987 and was operated intermittently until late September 1987, when Unit 4 was shut down for a scheduled maintenance outage.

Start-Up Experience and Results

The early operating period was characterized by intermittent operation due to problems encountered with the sorbent feed system and the necessity of incorporating design changes to attain full flow capability. Once this had been achieved, a particulate removal problem was identified and related to the high electrical resistivity of the ash produced with sorbent injection. This problem limited LIMB operation to 3 to 8 hours per injection period and made long-term, continuous operation impossible due to the need to maintain particulate emissions within the opacity limitations mandated by the Ohio EPA. Despite these time-consuming setbacks, a series of test runs were conducted over a 2-week period and valuable operating information and experience was obtained. The first test week was devoted to operation with a commercial, hydrated calcitic lime sorbent and the second to operation with the lime modified by the addition of calcium lignosulfonate. Typically, the first few tests of each week were characterized by inconsistent sorbent feed and operational upsets which had an impact on performance, while the tests during the latter part of each week were characterized by steady-state operation. Once handling problems were overcome, it appeared that a steady-state condition was reached very quickly after sorbent injection was begun and that this condition was representative of long-term operation. The results reported here focus on the data considered to be most reliable during the 2-week period and do not include transitional periods or times when operational upsets were know to occur. The 2-week test period does not provide a data base developed under rigorous statistical design, nor does it provide a definitive comparison between the normal commercial lime and the modified lime. However, the data are considered to be a reliable indicator of the type of results expected. As seen in Figure 3, a removal efficiency in the 55 to 60% range was obtained at a Ca/S stoichiometry of 2; the project goal of 50% removal appears obtainable at a stoichiometry of approximately 1.6. Future optimization of injection parameters is expected to improve the performance. Preliminary statistical analysis suggests that the modified hydrated lime exhibits slightly better performance. Since these early tests, the problems with the sorbent feed system have been corrected and a flue gas humidification system was designed, engineered, and installed. With the addition of the humidifier, LIMB can be operated in a continuous mode with modest water conditioning to enable reliable ESP operation, or with additional humidification to enhance SO_2 capture.

The humidification system is being operated for reliable ESP performance while the LIMB process is being optimized. Following LIMB optimization, the humidification system will be optimized for enhanced SO_2 removal and the total system operated continuously for 3-4 months.

As one the nine projects selected under the Clean Coal Technology Program, DOE has selected an extension to the LIMB wall-fired demonstration at Edgewater. This approximately 42-month program will provide a by-pass duct for EPA's humidification testing, an additional year of LIMB testing with up to 12 sorbent/coal combinations which include

humidification and simulated sorbent recycle, and an evaluation of CONOCO's coolside technology.

Tangentially Fired LIMB Demonstration

EPA initiated demonstration of LIMB technology on a tangentially fired utility boiler on June 12, 1987, with the signing of a contract with Combustion Engineering as the prime contractor. Over 50% of the program value is being provided by the industrial partners which include Combustion Engineering, Virginia Power Company, and Radian Corporation. Other industrial partners include Stone and Webster Corporation and C-E Lummus. The Government share of the funding is being provided by EPA and the Department of Energy.

In addition to the demonstration objective previously stated, the program will also evaluate the SO_2 removal enhancements achievable with flue gas humidification and sorbent reactivation and recycle.

The demonstration site is the 180 MW coal-fired Yorktown Unit 2 of Virginia Power Co. in Yorktown, VA. An intermediate sulfur content coal (about 2%) will be fired during the demonstration program. The T-fired demonstration is expected to span a total period of about 5 years, of which about 1 year will be dedicated to the LIMB performance evaluation.

The T-fired demonstration program consists of:

Task 1 :	Perform Program Management
Task 2 :	Develop Preliminary LIMB Concept
Task 2A:	Conduct site-specific preliminary studies
2B:	Develop demonstration performance objectives
2C:	Prepare preliminary process design
2D:	Prepare preliminary cost estimate
2E:	Prepare demonstration schedule
2F:	Present preliminary integrated LIMB concept for EPA evaluation
Task 3 :	Determine Baseline Conditions
3A:	Develop test plan
3B:	Conduct baseline tests
Task 4 :	Conduct Demonstration Program
4A:	Prepare detailed engineering design
4B:	Procure, install, and construct equipment
4C:	Operate system
4D:	Evaluate performance
Task 5 :	Prepare Recommendations and Guidelines for LIMB Commercialization
Task 6 :	Restore Site

The demonstration program field testing will be supported by mathematical modeling and pilot-scale testing at C-E Kreisinger Development Laboratory (KDL). These pilot-scale investigations will include aerodynamic flow modeling and testing on a 50 million Btu/hr Boiler Simulation Facility (BSF). The BSF, which is shown in Figure 4, was built for a prior program to develop criteria for the location and method of sorbent injection into tangentially fired coal-burning utility boilers. It models the time/temperature history, heat release rate, heat absorption, and aerodynamic characteristics of a large utility boiler.

The detailed work plan and quality assurance project plans were prepared and approved; baseline characterization tests of the Yorktown unit were performed with the focus being on documenting the temperature, velocity, and flow field characteristics of the host unit. This information, in turn, was used to design the cold flow model of Yorktown Unit 2. Detailed tests with this model were completed using smoke for flow pattern visualization, and methane injection as a tracer for detailed flow field description.

Similar cold flow modeling was performed using a model of the BSF. A series of cold flow modeling tests were conducted to verify the findings of the Yorktown cold flow model testing and to provide the necessary link to ensure correspondence between these facilities and the actual host unit.

The BSF was modified to incorporate key physical, heat transfer, and flow field characteristics of the Yorktown unit. Combustion tests were conducted using the coal and sorbent planned for use during the demonstration period.

Results from these cold flow and hot combustion tests are being used in the preliminary system design to locate sorbent injectors, determine proper injection velocities, and optimize injection patterns under various anticipated unit load conditions.

It is estimated that the preliminary integrated concept will be available for EPA review about April 1989 and equipment installation, construction, shakedown, and debugging will be completed about July 1990, at which time performance evaluation will be initiated and, including long-term operation, will be complete by late 1991. A final report is anticipated by mid-1992.

Large-Scale LIMB Prototype Evaluation[1]

The EPA and the Electric Power Research Institute (EPRI) are co-sponsoring and co-managing a 4-year program to evaluate sorbent injection technology on Richmond Power & Light's (RP&L's) Whitewater Valley Generating Station, Unit 2, in Richmond, IN. This unit is a 61 MW tangentially fired utility boiler constructed in 1973 (pre-NSPS) and was retrofitted in 1980 with the low-NO_x concentric firing system (12 burners). This unit is equipped with a Lodge Cottrell cold-side precipitator (SCA = 198) and also utilizes a Lungstrum air heater.

The objectives of the 3-phase program are:

1. To provide a utility-scale boiler which can be utilized to support an R&D testing program.

2. To provide a testing program to measure the relationship between SO_2 capture performance and different injection schemes using various coals, sorbents, and loads.

3. To evaluate the impact of LIMB technology on boiler performance and operability by testing over a wide range of conditions representative of U. S. utility boilers.

4. To provide a data base which can be used directly by the utility industry to apply these technologies to meet projected emission reduction requirements at minimum total cost.

Each phase will focus on one specific injection technology and will consist of periods for parametric testing, optimization testing, and long-term operational testing totaling about 4 months.

Phase I, the initial field evaluation, will involve upper furnace injection of calcium based sorbents with humidification upstream of the ESP to enhance ESP performance (see Figure 5). Contingent on results and availability of resources, the second and third field evaluations (Phases II and III) will be activated based on the status of the technology at that time.

Many activities to characterize the RP&L boiler have been completed. To support the upper furnace sorbent injection design, field measurements of temperature and velocity have been made, an isothermal model has been constructed, and heat transfer and jet mixing and dispersion models using RP&L conditions have been applied. These methodologies have been utilized to develop representative temperature and velocity profiles of the RP&L boiler and to support the design and development of the sorbent injection system for RP&L conditions.

Similar activities have been completed to support the humidification design. Field measurements of temperature and velocity were made within the duct, an isothermal model of the duct was constructed, and evaporation models used the RP&L conditions. In addition, an extensive nozzle evaluation program was completed to support the design of the humidification spray assembly.

The engineering design and equipment procurement of the sorbent injection and humidification system were completed, and installation was accomplished in August 1987.

Due to sorbent handling problems during the start-up period, satisfactory long-term steady-state operation of the sorbent injection system was not achieved. The humidification and sorbent injection systems were operational for periods of 4-6 hours under various short-term operating conditions. Under these short-term conditions, humidification was shown to enhance ESP performance during sorbent injection. Specific results and observations of these activities are reported in Reference 3.

As a result of the sorbent handling difficulties, start-up activities were terminated in December 1987; and an effort was initiated to analyze, redesign, and modify the material handling system. An industry survey was conducted to evaluate other experiences of the handling, transporting, and rate controlling of fine particle materials and a workshop was held in February 1988 to focus on material handling issues centered around the design and operation of equipment for the feed rate control and transport of the finely powered sorbents used in the LIMB process. The workshop also discussed issues relative to LIMB's impact on ESP performance. Participants included all major LIMB contractors, EPRI, and a Canadian utility, Saskatchewan Power. Participants openly shared prototype and large-scale experience focusing on these two topics followed by discussion of various technical approaches.

Installation of the redesigned material handling system was completed in August 1988 and start-up was initiated. Parametric testing to evaluate multiple sorbents, coals, and sorbent injection schemes at various operating loads of the furnace started in September and will continue until the end of the year 1988.

Following a winter shutdown, testing will be resumed about March 1989 and culminate with a continuous 2-week run in May 1989. A Phase I report is expected in December 1989.

E-SO_x

E-SO_x is a retrofit process, which combines ESP technology for collecting particles and spray dryer technology for SO_2 removal in a single unit, for coal-fired boilers. The process makes use of a modified existing ESP with an auxiliary system for preparation and injection of a sorbent slurry into the ESP.

In the E-SO_x concept, shown schematically in Figure 6, the front end of an existing ESP is converted to a spray chamber where contact is made between gaseous SO_2 and wetted lime particles. Evaporation of the water also takes place in this converted section of the ESP so that the reaction product, excess lime, and fly ash which enter the remainder of the ESP are sufficiently dry for efficient ESP operation. The electrical components of the remainder of the ESP are left intact so that it operates as a particle collector. To provide this contacting chamber with a sufficient space to allow a finite drying time of 1 second or greater, the ESP will most likely lose 25-30% of its collector plate surface. At the same time, the particulate load will increase by a factor of three or more. This particulate, a large fraction of which is calcium based, has high electrical resistivity. The sorbent reaction with SO_2 will eliminate sulfur trioxide (SO_3) effects that would tend to lower this resistivity. On the other hand, lowering of the gas temperature by the water spray will compensate for resistivity increases due to ash composition. Advanced ESP technology is available to aid in maintaining good performance in particulate collection. Cold pipe precharging and large diameter electrodes, for example, can be introduced in retrofitting ESPs to compensate for less collector surface or changes in resistivity characteristics.

The current program is sponsored by EPA and the Ohio Coal Development Office (OCDO) with cost-sharing from Babcock & Wilcox (B&W), the prime contractor, and Ohio Edison, the host site utility company. The program consists of laboratory and pilot R&D performed by EPA, B&W, and Southern Research Institute directed toward the objective of demonstrating the feasibility of E-SO_x technology on a 5 MWe equivalent utility boiler flue gas slipstream at Ohio Edison's R. E. Burger Plant in Dilles Bottom, OH. Successful application of this technology on a 5 MWe system is expected to demonstrate that:

1. A minimum of 50% SO_2 removal can be achieved from combustion of coals with sulfur contents typical of those fuels burned in Ohio at economical stoichiometries.

2. Operation in particulate compliance for existing units can be achieved with particulate emissions of less than 0.1 lb of particulates/million Btu of coal fired.

3. The E-SO$_x$ process will cost $100/kW less than wet FGD.

4. ESP reliability and operability can be maintained at the levels prior to the retrofit of the E-SO$_x$ system.

5. Technical difficulties such as changes in ash disposal requirements can be resolved in a cost-effective manner.

The program consists of:

Task 1	Project Management
Task 2	B&W Planning and Research
Task 3	EPA Engineering and Research
Task 4	EPA System Performance Studies
Task 5	System Design Development
Task 6	Pilot Plant Installation
Task 7	Field Pilot Testing
Task 8	Technical Reporting
Task 9	Site Restoration

Experimental effort has focused on addressing the fundamental issues of the E-SO$_x$ concept: 1) the feasibility of removing substantial SO_2 from the rapidly moving gas in contact with slurry droplets and drying the droplets before the gas enters the first electrical section of the ESP, and 2) maintenance of an acceptable level of ESP performance under a reduced collector area and an increased particulate loading.

A number of small pilot tests were performed at EPA to evaluate these issues. As shown in Figure 7, SO_2 removal improved as approach to saturation temperature decreased and stoichiometric ratio increased.

At extremely low approach temperatures, good removal is obtained at very low ratios. However, moisture in the ESP ash limits the lowest approach temperature to 28-30°F. Stoichiometric ratios of 1.3 to 1.4 produced a removal of 50% or better at a 30°F approach to saturation.

With respect to ESP performance, efficiencies of 99% and above were obtained even in the face of a 4-fold increase in particulate loading and a 50% reduction in ESP SCA. The high efficiency is attributable to several factors taken together. Evaporation of water during the drying step makes E-SO$_x$ a relatively low temperature process and, as a result, the high electrical resistivity of lime sorbent/fly ash mixtures is not encountered in E-SO$_x$. Figure 8 shows how the resistivity of E-SO$_x$ particulate drops to low levels below 150°F. As a consequence, back corona is not a problem. There are other reasons for good ESP performance. A large fraction of the lime particulate and the reaction product particulate are relatively large particles. They tend to fall out in the spray chamber or to be collected in the first stage of the ESP, presenting no removal burden on the ESP. Another significant contribution to good performance may be in the use of a cold-pipe pre-charger (CPP). Although the CPP's primary function of lowering the temperature of the dust layer collected on the cooled surface was not

needed, it serves as an efficient collector of low resistivity dust in contrast to the small space it occupies in the ESP.

In summary, basic concepts of the E-SO_x process have been verified at small pilot scale with a simulated flue gas. Removal of 50% or more of the SO_2 emitted from a boiler burning a 2.5-3% sulfur coal appears to be a reasonable goal. At the level of lime usage required and the observed performance of the shortened EPA in-house ESP, experimental evidence appears to verify ESP performance. Installation of the 15,000 acfm pilot ESP at the Burger Plant was initiated in May and checkout and shakedown testing will be completed by the end of the year. Following configuration testing for baselining, etc., parametric and operability testing will be performed and a final test report is expected about November 1989.

ADVACATE Process

The ADVAnced SiliCATE process was co-developed by the University of Texas, EPA, and Acurex Corporation. Fundamental chemistry of the fly ash/lime reaction has been discussed previously[5,6] and is summarized by the following reaction:

$$WH_2O + \frac{Z-X}{2} O_2 + XCaO + YSi\ (ag.) \rightarrow Ca_xSi_yO_z.WH_2O$$

where the product silicate is preferably a semi-crystalline mixture of silicates with considerable water of hydration. Because of the high surface area of calcium silicates, when slurried with excess calcium under proper conditions, they exhibit both high reactivity toward acid gases and considerable (25-40% by weight) moisture carrying capability, yet remain a non-sticking, free-flowing powder.

Figure 9 shows a typical process configuration where calcium is introduced to the process as a furnace injected sorbent. Similar schemes result for processes where calcium is introduced with the fuel impurities, as in Western coals. For low alkalinity coals, lime may alternatively be introduced into the hydrator; hence, the ADVACATE functions as an independent process or in conjunction with a furnace injection (LIMB) process.

Pilot plant simulations have been made at EPA's Research Triangle Park facilities and the results are shown in Figure 10. For an in-duct process of 0.75 to 2.0 sec residence time, typical sorbent utilizations are 50% up to a calcium to sulfur molar ratio of 1.5. With a fabric filter, sorbent utilizations approach 90% at substoichiometric calcium to sulfur ratios. All data shown reflect an approach to saturation at 20°F and product recycle at ratios typically two parts recycle to one part product throwaway. For the simulations, a spray dryer was used upstream to humidify gas to about 50-60°F approach, and sorbent moisture cooled gases to 20°F approach. In a commercial configuration, either heat exchangers or an increased recycle ratio could be used to eliminate auxiliary humidification entirely.

Other observed advantages are: (1) lower pressure losses in fabric filtration, (2) no in-duct agglomeration, and (3) no apparent deterioration of ESP performance despite greatly increased dust loadings. In EPA's in-house pilot plant, generally 1 to 2 hours or more are required

for the pressure drop to reach 3 in. w.g., compared to 15-30 min. for lime at similar calcium to sulfur ratios. This is easily explained by the fact that commercial calcium silicate makes a very porous filter cake and is, in fact, used as a filter aid. For this reason, no in-duct agglomeration of solids has been experienced, except where in-duct water spray or steam injection directly into the silicates has been attempted.

Depending on recycle ratio, silicate injection will increase the dust loading severalfold; however, the combination of duct humidification and modified sorbent has not been observed to diminish precipitator performance as observed by plume opacity. It has been observed that most silicate materials are collected in the first stage; therefore, we conclude that any retrofit precipitator application would, at most, require increasing hopper size and dust transport capability in the first stage. We similarly expect no degradation of performance in fabric filter collectors.

Currently, the process is being negotiated for a licensing agreement with a major worldwide pollution control vendor. On-going and near-term efforts include 1500-3000 acfm pilot evaluation at the Edgewater demonstration site, development of a continuous pressure hydration step for sorbent production, use of additives for simultaneous in-duct NO_x control, and pilot application to municipal waste incinerator flue gas for $HCl/SO_2/NO_x$ control.

References

1. P. S. Nolan and R. V. Hendriks, "Initial test results of the limestone injection multistage burner (LIMB) demonstration project." Presented at the 81st Annual Meeting of the Air Pollution Control Association, Dallas, TX (June 1988).

2. R. D. Stern, "EPA's program for evaluation and demonstration of low-cost retrofit LIMB technology." Presented at the Fourth Annual Pittsburgh Coal Conference, Pittsburgh, PA (October 1987).

3. G. C. England, et al., "Field evaluation of humidification for precipitator performance enhancement." Presented at the Seventh Symposium on the Transfer and Utilization of Particulate Control Technology, Nashville, TN (March 1988).

4. L. S. Hovis, et al., "E-SO_x system for combined particulate and SO_2 control." Presented at the Seventh Symposium on the Transfer and Utilization of Particulate Control Technology, Nashville, TN (March 1988).

5. W. Jozewicz, et al., "Development and pilot plant evaluation of silica-enhanced lime sorbents for dry flue gas desulfurization, JAPCA 38:796-805 (1988).

6. W. Jozewicz, et al., "Reactivation of solids from furnace injection of limestone for SO_2 control," Environ Sci. Technol., 21:664 (1987).

*Readers more familiar with the metric system may use the following conversion factors:

From	To	Multiply By
acfm	m^3/min	0.020832
ft^2	m^2	0.09290
in.WG	kg/m^2	0.002540
lb/hr	kg/h	0.45359
$lb/10^6$ Btu	ng/J	429.94
ton	t	0.90718
°F	°C	°C=(5/9) (°F-32)

Acknowledgements

The writer gratefully acknowledges the support of: the Ohio Edison, Virginia Electric Power, and Richmond Power & Light utility companies (for being partners and hosting our field evaluations and demonstrations); other partners in these programs, particularly the Department of Energy, the Ohio Coal Development Office, the Electric Power Research Institute, CONOCO, the Babcock & Wilcox Company, Combustion Engineering, Energy and Environmental Research, and Acurex Corporations; contractors and subcontractors working diligently on these programs; and EPA's Project Officers, namely Robert V. Hendriks, David G. Lachapelle, P. Jeff Chappell, Louis S. Hovis, and Charles B. Sedman. The writer also appreciates the assistance of these individuals in the preparation of this paper.

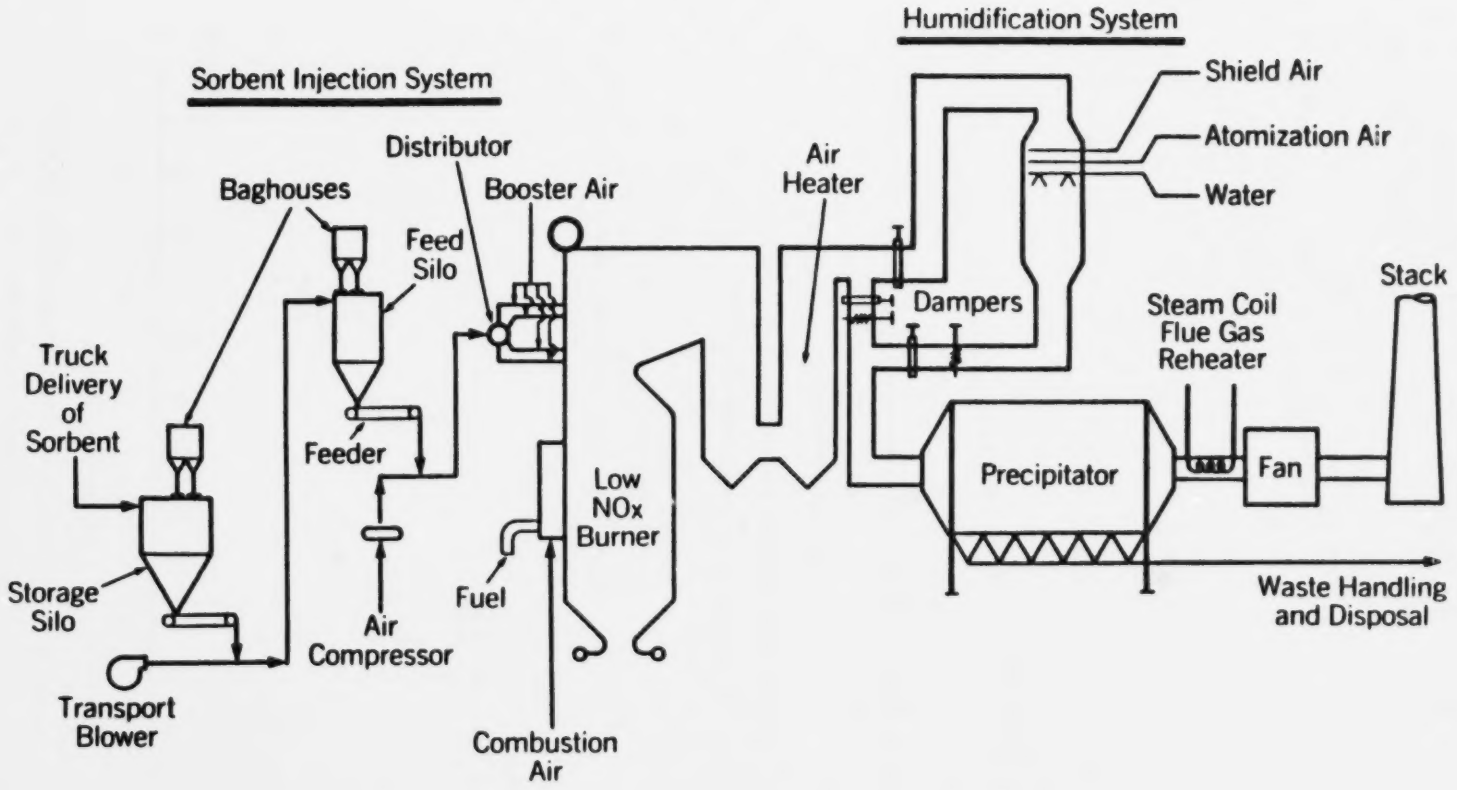

Figure 1. LIMB process flow diagram.

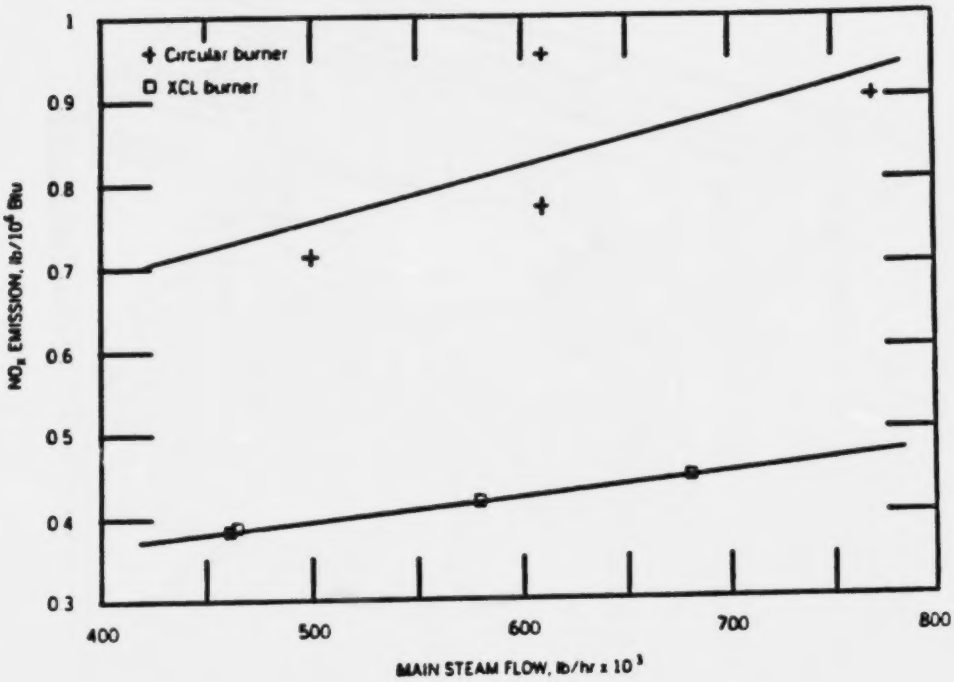

Figure 2. NO_x emission as a function of boiler load.

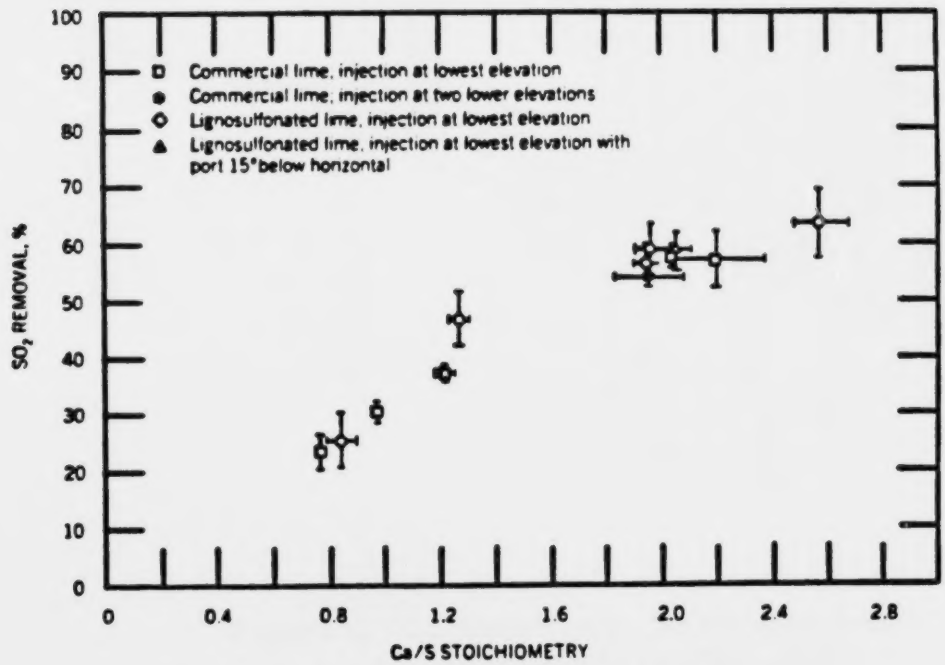

Figure 3. Sulfur dioxide removal efficiency as a function of calcium/sulfur stoichiometry.

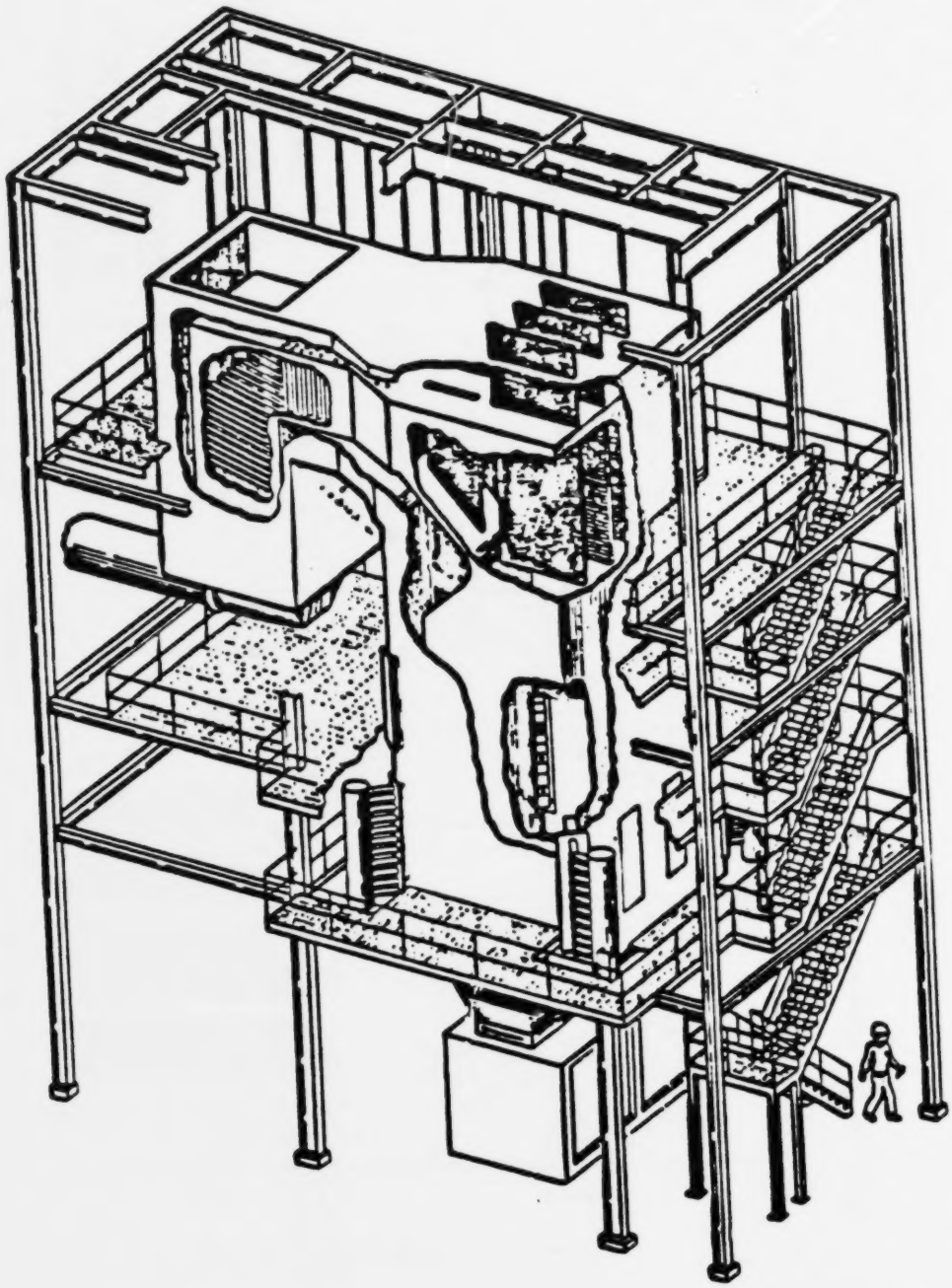

Figure 4. Combustion Engineering's boiler simulation facility (BSF).

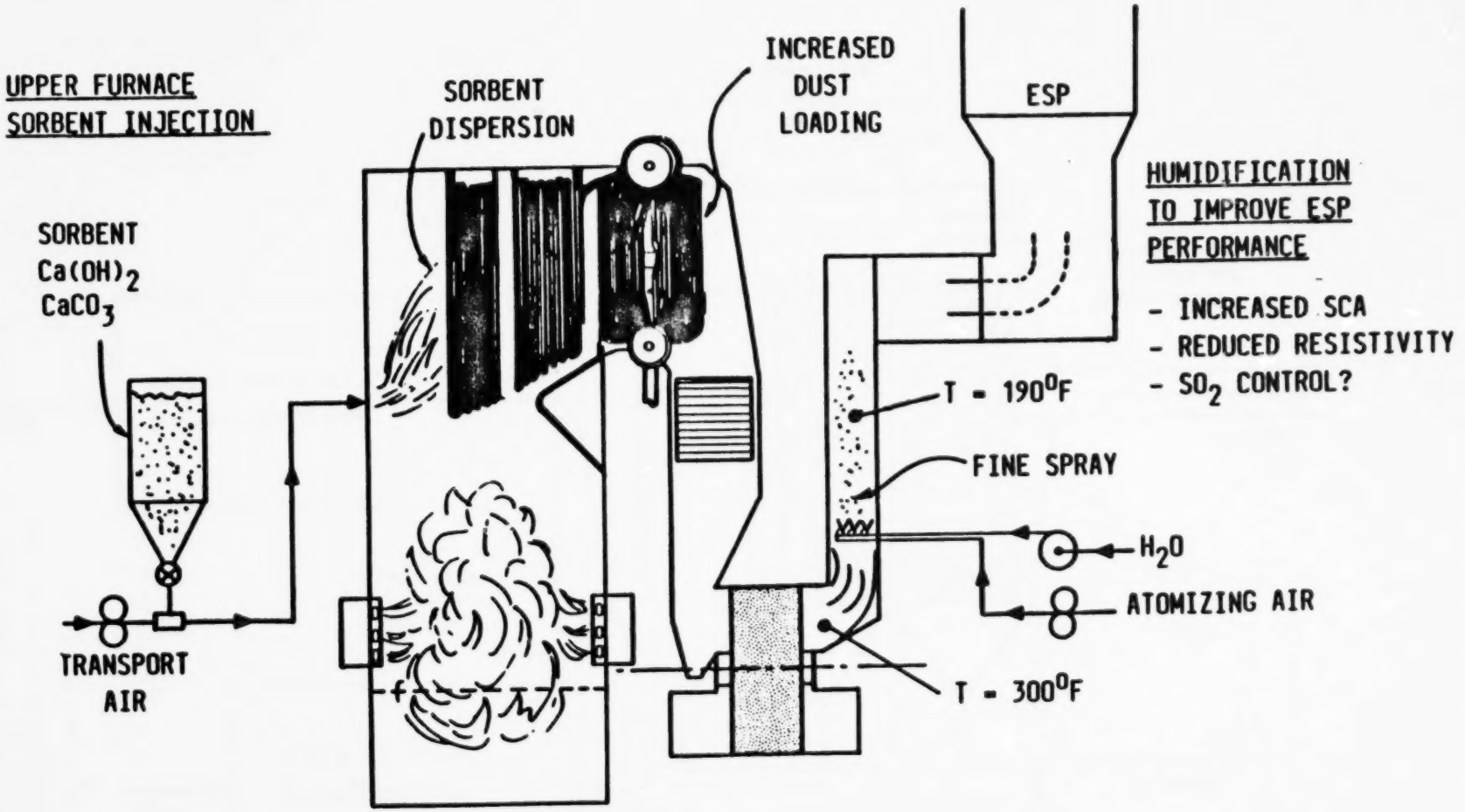

Figure 5. Phase I sorbent injection with humidification for ESP improvement.

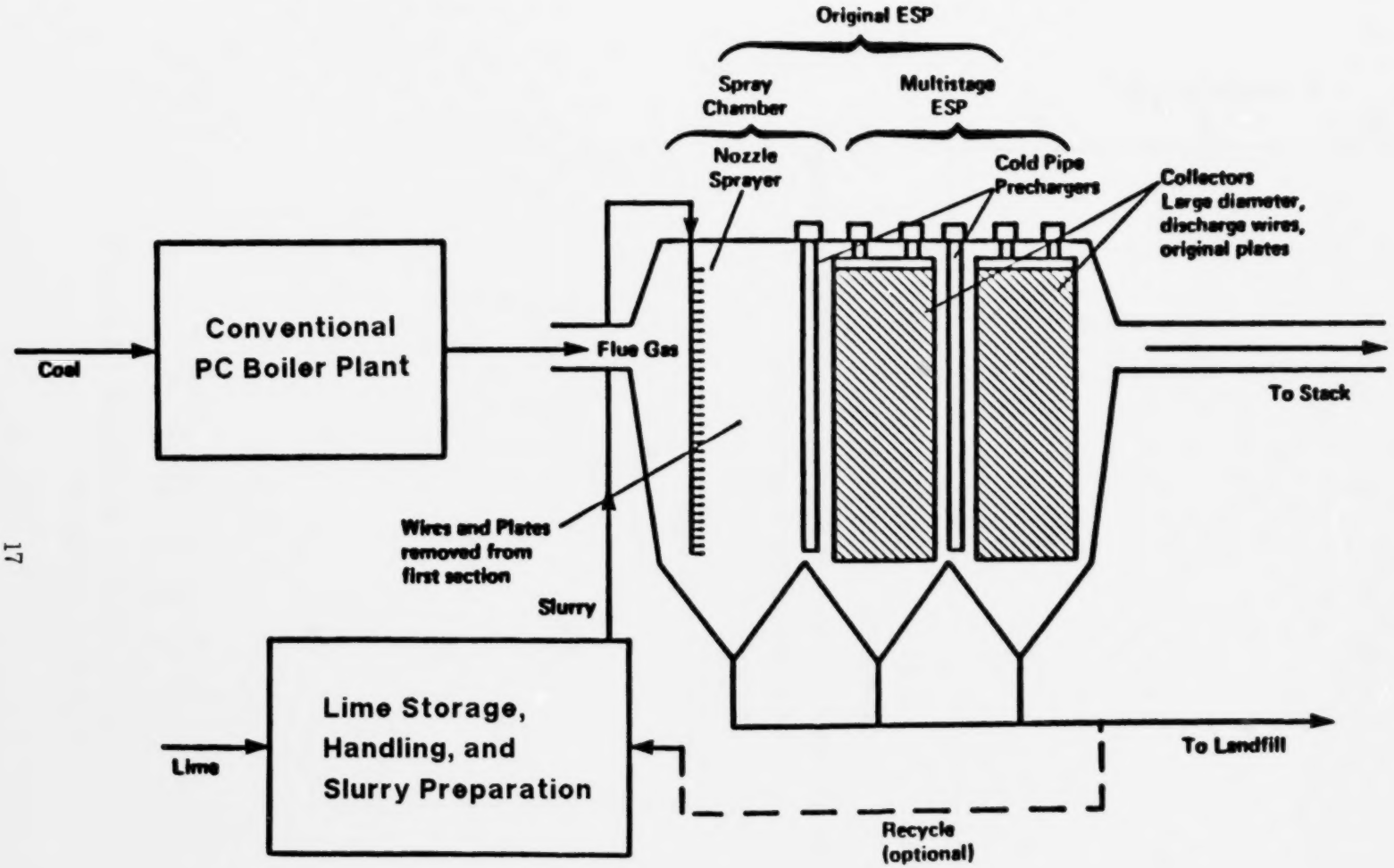

Figure 6. Schematic diagram of E-SO_x process.

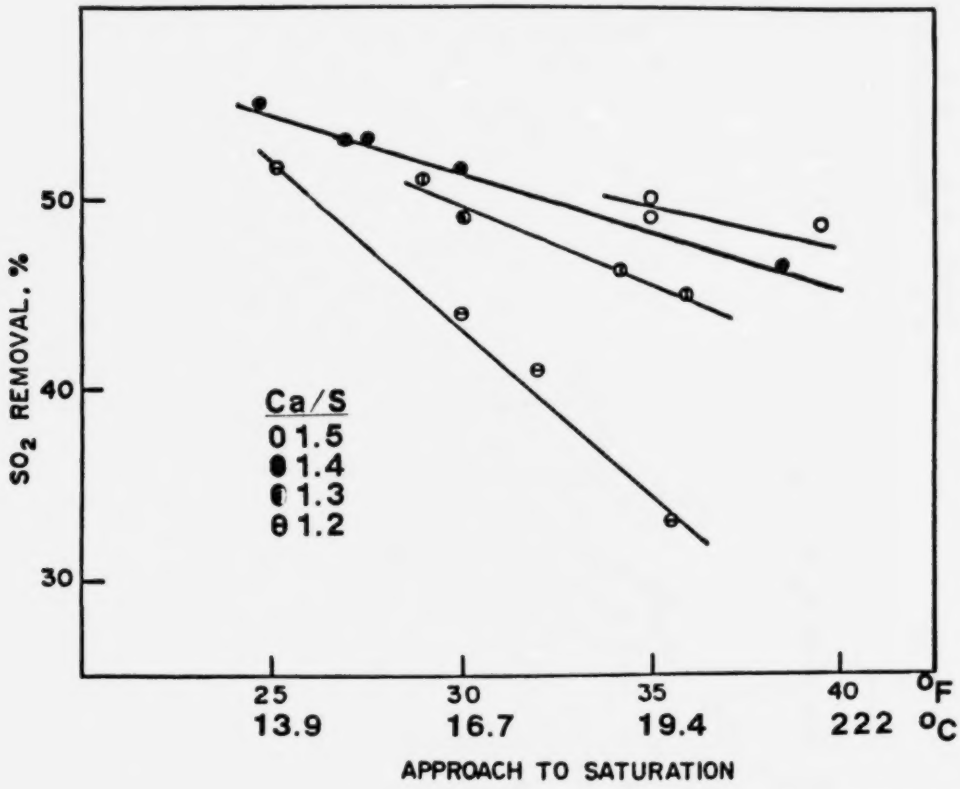

Figure 7. Effect of approach temperature on SO_2 removal at several stoichiometric ratios.

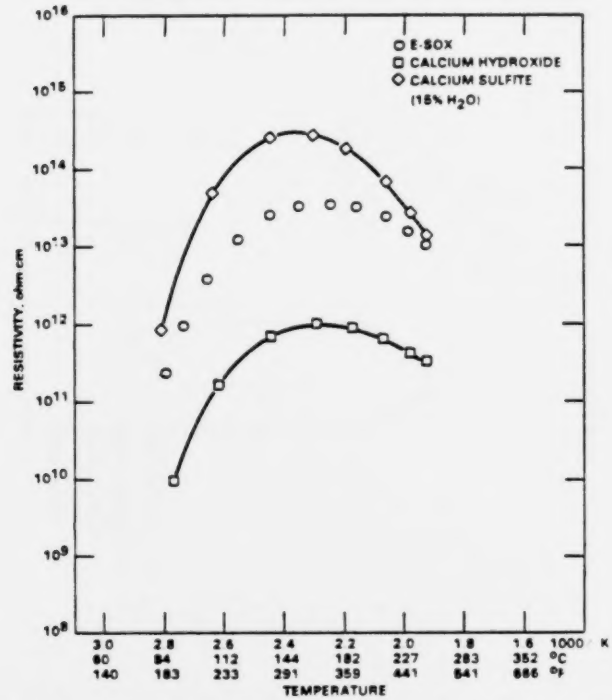

Figure 8. Resistivity of E-SO_x sample compared to sample components.

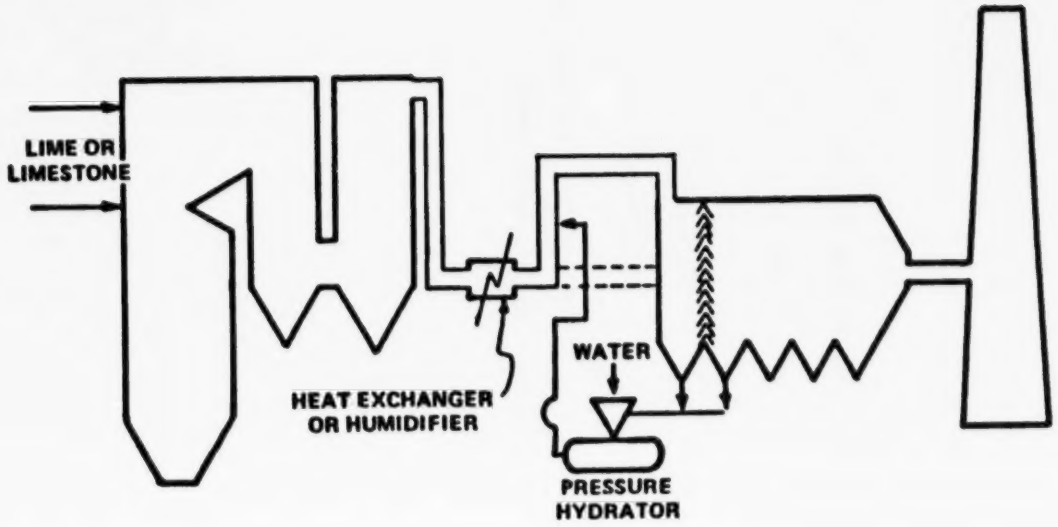

Figure 9. Furnace injected sorbent with coolside ADVACATE.

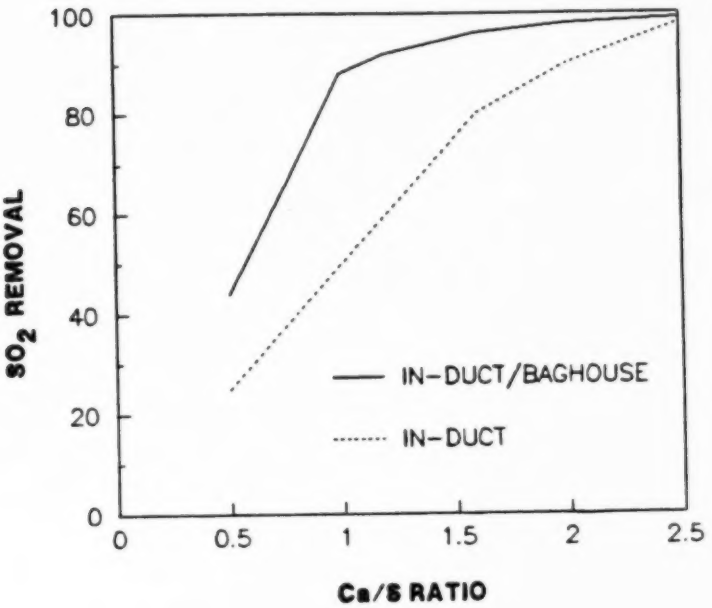

Figure 10. SO_2 removal vs. stoichiometric ratio calcium silicate damp injection.